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**13. ABSTRACT** *(Maximum 200 words)*

A goal of the research project was to develop the modified diakoptic theory into an efficient method for analyzing and designing antenna structures and distributed parameter circuits. A second goal of the project was to develop the numerical methods needed to implement the analysis techniques. And a final goal was to perform laboratory measurements whose date enable one to corroborate the accuracy of the theoretical/numerical methods of the modified diakoptic theory. The three goals have been realized. The final report summarizes these efforts.

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ANALYSIS AND DESIGN OF ANTENNA STRUCTURES -- DIAKOPTIC THEORY AND THE MOMENT METHOD

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Final Report

by


Chalmers M. Butler

Electrical and Computer Engineering


November 1990


U. S. ARMY RESEARCH OFFICE
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Contract DAAL03-86-K-0020



Clemson University
Clemson, SC 29634-0915

## 1. STATEMENT OF PROBLEM AND SUMMARY OF RESULTS

A goal of the research project sponsored by ARO under Contract DAAL03-86-K-0020 was to develop the modified diakoptic theory into an efficient method for analyzing and designing antenna structures and distributed parameter circuits. A second goal of the project was to develop the numerical methods needed to implement the analysis techniques. And a final goal was to perform laboratory measurements whose data enable one to corroborate the accuracy of the theoretical/numerical methods of the modified diakoptic theory. The three goals have been realized.

For several types of rather general antennas, the modified diakoptic theory offers an advantage over the traditional integral equation methods, in that *a priori* calculations can be performed which enable one to significantly reduce the rank of the system of linear equations to be solved or, equivalently, the rank of the impedance matrix to be inverted. The solution technique developed for complex wire structures is sufficiently general that it can handle any thin-wire, multielement antenna of moderate size, which resides in homogeneous open space. The wires may be curved and of specified length, radius, and contour, with the contour of the wire being either entirely a smooth curve or a curve having a number of sharp bends. The structure may have closed loops, multiple

junctions, and multiple feeds and/ or loading. Examples for which excellent results have been obtained by the modified diakoptic theory are simple wire arrays, folded dipoles, "T" and "L" antennas, general top-loaded monopoles, and, most recently, Yagi-Uda arrays of wires.

Simple wire antenna structures which reside above or below the interface between two dissimilar half spaces have been successfully analyzed by the modified diakoptic theory. Full account has been taken of the Sommerfeld integral portion of the integral equation kernel in such analyses.

In addition to the efforts to develop an efficient method for analyzing wire and wire-like structures, attention also has been focused upon methods for analyzing structures formed by conducting traces on substrates, with emphasis on the type passive components that find wide application in microwave monolithic integrated circuits (MMIC) as well as in other microcircuits. These include microstrip components printed on grounded substrates which are made up of narrow strip conductors having single or multiport excitation as well as simple strip and wire configuration above the grounded substrate. Depending on the actual geometry and size relative to wavelength of the structures, these components may be classified as antennas or distributed circuits or as combinations of both in a single unit. In any event, the development of the modified diakoptic theory and the associated numerical implementation has led to an efficient analysis tool for

these structures.

In order to support the results obtained from the theory and the attendant numerical methods developed during the course of the research effort, experiments were conducted on a few representative wire structures and configurations comprising conducting traces on grounded substrates. In the case of the wire structures, models were constructed and erected over an image plane, and admittances were measured and compared with calculated results. Results from simple bent and curved wires, from top-loaded monopoles, and from antenna arrays have revealed that the theoretical data obtained from computations are highly accurate . Rudimentary experiments were performed on microstrip structures in order to lend support to the theory applied to this class of antennas and/or circuits. Several models were fabricated by photo etching techniques.

The modified diakoptic theory is an extension of the diakoptic theory developed by Goubau. It also may be looked upon as a refinement of the method of moments. An important advantage of the modified diakoptic theory applied to antenna and circuit structures, over presently available solution procedures, is that one can solve a given problem with a smaller matrix than would be needed in a technique based upon one of the traditional methods. This means that computer implementation efficiency obtains in the methods developed in the present contract effort. Consequently, the modified diakoptic technique allows one

either to achieve greater accuracy or to analyze larger structures than is possible with available methods. Of course, the precise enhancement of accuracy and/or structure depends on the details of the structure under consideration. In this regard, it should be mentioned that to be amenable to analysis by the modified diakoptic theory, a structure must be such that it can be "diakopted" (sliced, in the case of a conductor) into smaller substructures, each separated from its immediate neighbor by a port at which a voltage and a current can be defined. Research results achieved to date in the development of solution techniques based on the modified diakoptic theory applied to the type structures mentioned above indicate that an appreciable enhancement of accuracy or an increase in size is, indeed, realizable. In addition, as a minor by-product, the modified diakoptic theory is more understandable to a typical engineer than is the moment method.

## 2. PUBLICATIONS, THESES, AND REPORTS

The following journal article, conference papers, presentations, theses, and informal technical report have resulted from the work accomplished under sponsorship of ARO Contract DAAL03-86-0020. Additional journal articles are in review and under preparation and, of course, will be reported upon when appropriate.

Journal Article:

> F. Schwering, N. N. Puri, and C. M. Butler, "Modified Diakoptic Theory of Antennas," IEEE Transactions on Antennas and Propagation, vol. AP-34, no. 11, pp. 1273 - 1280, November 1986.

Conference Papers:

> C. M. Butler and R. G. Kaires, "Analysis of curved-wire antennas by means of the modified diakoptic theory," Proceedings, 1989 URSI International Symposium on Electromagnetic Theory, Stockholm, August 1989.

> C. M. Butler, "Diakoptic theory and the moment method, " 1990 IEEE Antennas and Propagation Society International Symposium and URSI National Radio Science Meeting, Dallas, TX, May 1990.(invited paper)

Conference Presentations:

> C. M. Butler and F. Schwering, "The Modified Diakoptic Theory and the Moment Method for Analyzing Wire-Structure Antennas," Meeting Digest, URSI National Radio Science Meeting, Boulder CO, January 1987.

> Butler, C.M., W.A. Walker, R.G. Kaires, and F. Schwering, "Computational methods in the diakoptic analysis of a cylindrical antenna," Meeting Digest, p. 13, URSI National Radio Science Meeting, Boulder, CO, January 1988.

> C. M. Butler, R. G. Kaires, and W. A. Walker, "A systematic analysis of straight-wire antennas by means of the modified diakoptic theory," Meeting Digest, 1989 URSI National Radio Science Meeting, Boulder, CO, Jan. 1989.

R. G. Kaires and C. M. Butler, "Analysis of a wire antennas over the earth by means of the modified diakoptic theory," Meeting Digest, 1989 IEEE Antennas and Propagation Society International Symposium and URSI National Radio Science Meeting, San Jose, CA, June 1989.

W. A. Walker and C. M. Butler, "Analysis of multiple-junction wire antennas by the modified diakoptic theory," Meeting Digest, 1989 IEEE Antennas and Propagation Society International Symposium and URSI National Radio Science Meeting, San Jose, CA, June 1989.

D. F. Taylor and C. M. Butler, "Convergence of open-port currents in the modified diakoptic theory," Meeting Digest, 1990 URSI National Radio Science Meeting, Boulder, CO, Jan. 1990.

D. F. Taylor and C. M. Butler, "A modified diakoptic theory analysis of a top-loaded antenna," Meeting Digest, 1990 URSI National Radio Science Meeting, Boulder, CO, Jan. 1990.

R. G. Kaires and C. M. Butler, "Analysis of conducting strip radiators on grounded slabs by means of the modified diakoptic theory," 1990 IEEE Antennas and Propagation Society International Symposium and URSI National Radio Science Meeting, Dallas, TX, May 1990.

Theses:

Ph.D.

R. G. Kaires, "Analysis of Narrow Conducting Strips on a Grounded Dielectric Slab by means of the Modified Diakoptic Theory," Ph.D. Thesis, Clemson University, Clemson, SC, 1989.

M.S.

D. F. Taylor, "Modified Diakoptic Analysis of Thin Wire Antennas," M.S. Thesis, Clemson University, Clemson, SC, 1990.

Report:

Kaires, R. G., and C. M. Butler, "Analysis of Narrow Conducting Strips on a Grounded Dielectric Slab by means of the Modified Diakoptic Theory," ARO Research Report (Contract DAAL03-86-K-0020), Clemson University, Clemson, SC; April 1990.

(Two copies of the above "informal" technical report, which including many details not appropriate for journal papers, were submitted to Dr. J. W. Mink and to Dr. F. Schwering (U. S. Army Comm R & D Command -- DRDCO-COMM-RM-4, Fort Monmouth) on May 30, 1990.)

## 3. SCIENTIFIC PERSONNEL

Below is a list of scientific personnel associated with activities sponsored by ARO Contract DAAL03-86-0020. D. F. Taylor (see below) was not supported from funds made available through the contract but did conduct research pertaining to the contract activity.

Principal Investigator:

Chalmers M. Butler

Ph. D. Students:

| | |
|---|---|
| R. G. Kaires | Ph.D. degree awarded 1989 |
| W. A. Walker | resigned |
| C. C. Courtney | in progress |
| P. D. Mannikko | in progress |

M.S. Student:

| | |
|---|---|
| D. F. Taylor | M.S. to be awarded in 1990 |